Magnetic-Based Sensors Review and Applications to Tactile Sensing

Cameron Weigel, February 15, 2022

Progression in tactile sensing elements has increased dramatically due to novel manufacturing techniques and low-cost, powerful computing. This report will discuss the recent advances made in magnetic-based sensing techniques utilizing Hall effect sensors and their applications. We will begin by discussing the construction of Hall effect sensors pertaining to robotics and recent advancements in computation methods related to them [1,2]. Next, a few applications of Hall effect sensors will be discussed, in particular, applications in biomedical robotics. Applications discussed will be rehabilitation robotics related to wrist rehabilitation [3], and sensorized splinting of arthritic joints as a method of improving joint pain [4]. We will conclude the report with limitations of magnetic sensors and potential future research applications of them.

The Hall effect is the development of a transverse electric field in a solid material when it carries an electric current and is placed in a magnetic field that is perpendicular to the current [6]. The Hall field creates an accumulation of charge on one side of the conductor, producing a difference in potential [6]. The Hall effect produces relatively small voltage differences that have not been easily isolated until recent developments in semiconductor manufacturing [7]. In tactile sensing applications, we can suspend a magnet in a known flexible medium, and utilize the Hall effect to measure force based on the displacement of the magnet. This force can be calculated through experimental methods such as utilizing machine learning algorithms like k-nearest neighbors [1] in addition to traditional calibration methods, i.e. force gauges, scales, etc, with filtering algorithms such as the Savitzky-Golay filter [2].

Advances in manufacturing have been a boon to the development of low-cost sensors. Magnetic sensors have only recently seen widespread adoption because of advances in semiconductor manufacturing [9]. One particular advancement in the research of magnetic based sensing technologies is the development of graphene-based Hall-effect sensors [9]. With advancements made in the production of pure graphene, a material known for its particularly useful properties as semiconductors constructed from a single layer of carbon atoms [9]. Additionally, because of graphine's high mechanical and electrical stability; flexible, wearable graphene-based electronics have been developed [9]. Hall effect sensors in particular have seen the benefits of graphene-based electronics [10].

Not only have advances in manufacturing methods aided in the effectiveness of magnetic based sensing, but equally important advances have been made in the computational methods of relating experimental applied forces to the measured output. Utilizing algorithms such as k-nearest neighbors, researchers were able to achieve highly accurate readings of both an applied force and position of said force [1]. From [1], the computational model was able to achieve force position readings with an accuracy of 94% to 96% when applying their design to the fingertips of an Allegro robotic hand [8]. Another equally important advancement is the simulation of applied forces through computational methods such as finite-element analysis. Through proper simulation of forces applied to soft mediums, researchers can accurately compute the physical requirements of their magnetic-based sensing devices [4].

Current research applications involving magnetic-based sensors span numerous fields, the scope of this paper will focus on just a few applications in biomedical robotics. A particular field of research that is utilizing soft, tactile, magnetic sensors is the field of rehabilitation robotics [3,4]. With small form-factor sensors, researchers are able to accurately locate both perpendicular, and tangential contact forces from a magnetic sensor. Additionally, with the recent explosion of 3D printing technology, researchers can also quickly and cost-effectively create custom molds for their sensing technology [2,3,4].

Splinting of injured joints is a means of reducing both pain and recovery time by limiting mobility of the affected area. Since effective splinting of injured joints is an underdeveloped field, the application of sensors to splints can hopefully shed light on optimal methods of splinting [4], which would lead to a further reduction in pain and recovery time. Through finite element analysis simulations, previous research, and experimentation, researchers were able to create a sensorized splint prototype that can detect pressures and shear forces imparted on the splinted joint [4]. The design of the sensor utilized a soft, silicone medium to suspend magnets above an array of hall effect sensors. 3D printed molds and mounting brackets affixed a 12mm diameter custom PCB behind a silicone mold that encapsulated several permanent magnets [4]. This whole assembly was then fit to a wrist splint. Force readings were then measured by experimenting with different hand postures and comparing it to a commercial load cell. The final outcome of the paper was positive, showing that these soft sensors could be applied to splinting applications to better understand the forces imparted on joints.

Another application in biomedical robotics that utilized magnetic-based sensors was the construction of a series elastic actuator for a compliant parallel wrist rehabilitation robot [3]. In the case of this paper, the Hall effect sensor was used in conjunction with load cells for calibration, illustrating a recurring importance to the fusion of multiple sensor types to create an accurate model. Building upon existing work from the developed RiceWrist [11], researchers developed a force-feedback, series elastic wrist rehabilitation robot [3]. Again, results were positive, researchers were able to develop a compliant and accurate rehabilitation robot prototype.

There are still many improvements to make in the field of hall-effect based tactile sensing. Some downsides to these types of tactile sensors are their reliance on a compliant medium with nonlinear deformation mechanics that result in complex algorithms (in addition to experimental data) required to properly relate forces imparted on the medium to sensor readings. Additionally, Hall effect sensors only work in selected ranges of operation, are susceptible to thermal changes, and can give false readings in the presence of another magnetic field. These are just a few reasons why it is necessary to fuse multiple streams of sensor data to achieve a holistic depiction of real world scenarios. There are many pathways one can take in regards to future research on magnetic-based sensing technologies. For example, the design and manufacturing of graphene-based sensors, or the optimal design of soft magnetic array sensors, or the filtering and machine-learning based algorithms to accurately describe the forces imparted on the sensor.

Citations

1. Mohammadi A, Xu Y, Tan Y, Choong P, Oetomo D. Magnetic-based Soft Tactile Sensors with Deformable Continuous Force Transfer Medium for Resolving Contact Locations in Robotic Grasping and Manipulation. Sensors. 2019; 19(22):4925. [Link]
2. Tomo TP, Somlor S, Schmitz A, Jamone L, Huang W, Kristanto H, Sugano S. Design and Characterization of a Three-Axis Hall Effect-Based Soft Skin Sensor. Sensors. 2016; 16(4):491. [Link]
3. F. Sergi, M. M. Lee and M. K. O'Malley, "Design of a series elastic actuator for a compliant parallel wrist rehabilitation robot," 2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR), 2013, pp. 1-6, doi: 10.1109/ICORR.2013.6650481. [Link]
4. Jones D, Wang L, Ghanbari A, Vardakastani V, Kedgley AE, Gardiner MD, Vincent TL, Culmer PR, Alazmani A. “Design and Evaluation of Magnetic Hall Effect Tactile Sensors for Use in Sensorized Splints.” Sensors. 2020; 20(4):1123. [Link]
5. Infineon TLV493D 3D Magnetic Sensor https://www.infineon.com/dgdl/Infineon-TLV493D-A1B6-DataSheet-v01_10-EN.pdf?fileId=5546d462525dbac40152a6b85c760e80
6. “Hall Effect” https://www.britannica.com/science/Hall-effect
7. “Understanding and Applying the Hall Effect” https://www.allaboutcircuits.com/technical-articles/understanding-and-applying-the-hall-effect/
8. “Allegro Hand”, Wonik Robotics. https://www.wonikrobotics.com/research-robot-hand
9. Collomb D, Li P, Bending S, “Frontiers of graphene-based Hall-effect sensors” Journal of Physics: Condensed Matter, Volume 33, Number 24. [Link]
10. Wang. (2016). Encapsulated graphene-based Hall sensors on foil with increased sensitivity. Physica Status Solidi. B, Basic Research PSS., 253(12), 2316–2320. [Link]
11. Gupta A, O’Malley MK, Patoglu V, Burgar C. Design, Control and Performance of RiceWrist: A Force Feedback Wrist Exoskeleton for Rehabilitation and Training. *The International Journal of Robotics Research*. 2008;27(2):233-251. [Link]